Fatigue Reliability Assessment of Drill String Due to Stick-Slip Vibrations and Wave-Frequency Vessel Motions

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ABSTRACT

This paper presents an investigation of the reliable performance of the offshore drill strings subjected to separate and combined stick-slip vibration and wave-induced vessel motions, which have never been investigated before. A nonlinear finite element model of the coupled drill string and drilling vessel was developed to obtain the dynamic stress responses along the drill string. Reliability assessment was conducted by defining the normal, low, and high risk zones under different excitation scenarios imposed by operating parameters and environmental conditions. The study showed that the stick-slip vibration combined with the drilling vessel motions can significantly reduce the reliable performance of some regions of the drill string with regard to fatigue failure.

KEY WORDS: Drill string dynamics; fatigue; reliability; stick-slip vibration; response amplitude operator (RAO); finite element modeling; endurance limit.

INTRODUCTION

Offshore oil and gas drilling operations are extremely costly and impose further physical and functional challenges compared to onshore drilling. With a typical day-rate of $600,000 to $800,000 for a deep-water drilling rig in the offshore Gulf of Mexico (Amado, 2013), drill string failure can result in severe economic consequences (Macdonald and Bjune, 2007). Drill string failure is commonly caused by overload (tensile, torsional, or combined), fatigue, and corrosion (Gokhale et al., 2007). Despite the manufacturing and material improvements and significant advances in the inspection techniques, fatigue failure of drill strings continues to occur at a high frequency (Gokhale et al., 2007). The analysis of 76 drill string failures across three continents indicated that fatigue was the primary cause in 65% of the failures (Hill et al., 1992).

Fatigue is a non-reversible and cumulative phenomenon caused by cyclic loads, which initially appears in the form of microscopic cracks (Stephens et al., 2001). These cracks propagate within the drill string due to cyclic loads until they reach a critical dimension and eventually lead to catastrophic failure (Sathuvalli et al., 2005).

The primary fatigue loadings on drill string include dog-legs, mechanical vibrations, and motions of the floating drilling unit in response to the ocean waves (API-RP-7G, 1998). Dog-legs are the curved regions of the wellbore due to which the rotating drill string is bent and subjected to fully-reversed alternating bending stresses. The majority of fatigue accumulation assessments in the oil and gas field literature have concentrated on the fatigue failure of drill string due to dog-legs (i.e., combined axial and bending stresses), which were primarily evolved from the works of Lubinski (1961) and Hansford and Lubinski (1966) (e.g., Grondin and Kulak, 1994; Patel and Vaz, 1995; Wu, 1996; Sathuvalli et al., 2005; Gokhale et al., 2007; Sikal et al., 2008).

Mechanical vibrations, on the other hand, raise from the nonlinear impact and friction at the drill string-wellbore and bit-formation interfaces and can cause considerable cyclic stresses (Christoforou and Yigit, 2003). These vibrations manifest as axial (i.e., bit bounce), lateral (i.e., whirl), and torsional (i.e., stick-slip) dynamic motions, which can exist separately or couple together in a linear or nonlinear manner (Brett, 1992; Dunayevski et al., 1993). The quantitative comparison between fatigue damage of drill string due to mechanical vibrations and dog-legs revealed that the fatigue damage induced separately by axial and torsional vibrations was greater than that due to dog-legs (Patel and Vaz, 1995). Although extensive research works have been devoted to characterization of drill string dynamics under vibrations (e.g., Lin and Wang, 1991; Brett, 1992; Jansen and van den Steen, 1995; Richard et al., 2007; Navarro-Lopez and Cortes, 2007; Liu et al., 2013; Sampaio et al., 2007; Khulief et al., 2007; Ritto et al., 2009; Ghasemloonia et al., 2013; Liu et al., 2014; Kapitaniak et al., 2015; Moharrami et al., 2021), a few studies have investigated the vibration-induced fatigue of drill string. These studies include fatigue damage analysis under uncoupled axial, lateral, and torsional vibrations (Patel